Extracranial-intracranial bypass: Resurrection of a nearly extinct operation

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Background: **Giant intracranial artery aneurysms (GIAAs) are often not amenable to neurosurgical clipping or endovascular coiling. Extracranial-intracranial (EC-IC) bypass, a procedure that has been essentially abandoned for the treatment of intracranial ischemic disease, followed by parent vessel occlusion, is often successful in treating these aneurysms. Vascular surgeons should be familiar with this operation, especially in centers with neurosurgical capability.**

Methods: **A retrospective review of patients treated from 1990 to 2010 at New York University Medical Center was performed. Office and hospital records of all patients identified were reviewed with attention to the age and sex of the patient, presenting symptoms, preoperative testing, procedure performed, type of bypass conduit, graft patency, intraoperative and postoperative complications, length of follow-up, and overall outcome. EC-IC bypass was performed using a graft of great saphenous vein (GSV) or radial artery (RA). The vascular surgeon harvested the vascular conduit, tunneled the graft, and performed the extracranial anastomosis, and the intracranial anastomosis was performed by the neurosurgeon.**

Results: **A total of 36 patients (14 men, 22 women) underwent 37 EC-IC bypasses with 34 GSV and three RA grafts. The median age was 57 years (interquartile range, 49-66 years), and the median follow-up was 53 months (interquartile range, 29-77 months). Aneurysm location was the internal carotid artery in 30 patients, the basilar artery in three, and the middle cerebral artery in four. All 37 aneurysms were excluded from the cerebral circulation, with 33 grafts remaining patent at follow-up, as determined by serial cerebral or magnetic resonance angiogram. At follow-up, 33 of 34 of the GSV grafts (88%) and three of three (100%) of the RA grafts were patent. There were two deaths (5.6%), despite patent grafts. Postoperative graft occlusion led to homonymous hemianopsia in one patient and temporary hemiparesis in another (5.6%). Graft occlusions were asymptomatic in two patients.**

Conclusions: **EC-IC bypass is a safe and effective treatment for GIAAs, with acceptable rates of morbidity (5.6%), mortality (5.6%), and graft patency (89.2%). We suggest that the technique described in this report should be routinely used for treatment of GIAAs in centers where neurosurgery and vascular surgery services are available and should be considered a standard procedure in the armamentarium of the vascular surgeon. (J Vasc Surg 2012;56:1303-7.)**

Vascular surgeons have used extra-anatomic bypass for years in the treatment of extracranial aneurysmal and occlusive arterial diseases, with excellent results.[1-3] The treatment of intracranial arterial disease is usually deferred to neurosurgeons and neurointerventionalists[4-6]; however, vascular surgeons have historically treated certain intracranial arterial diseases, including high cervical carotid occlusions and giant intracranial artery aneurysms (GIAAs), as part of a multidisciplinary approach.[7-9] The role of the vascular surgeon in performing extracranial-intracranial (EC-IC) bypass usually includes harvesting the vascular conduit, tunneling the graft, and performing the extracranial anastomosis, and the neurosurgeon performs the intracranial anastomosis. In our institution, we have used this multidisciplinary approach in the treatment of complex GIAAs, with excellent results.[9]

The first EC-IC bypass was reported by Yasargil[10] in 1969, when he performed a bypass from the superficial temporal artery (STA) to the middle cerebral artery (MCA) for the treatment of a complex intracranial aneurysm. The procedure quickly gained favor in treating not only aneurysmal disease but also cerebrovascular disease that was not amenable to carotid endarterectomy.[11,12] Initial studies were promising, but in 1985, the randomized multicenter EC-IC Bypass Study failed to demonstrate a benefit of STA-MCA bypass vs the best medical therapy in the treatment of symptomatic atherosclerotic disease of the internal carotid artery (ICA), and its use sharply declined thereafter.[13] Although not commonly used to treat intracranial atherosclerotic disease, EC-IC bypass is still routinely performed in the treatment of GIAAs.[8,9,14] Vascular surgeons should be familiar with this operation, especially in centers with neurosurgical capability.

GIAAs are intracranial aneurysms with a diameter >2.5 cm.[15] GIAAs include the saccular type, characterized by a relatively small neck, and the fusiform type, which are predominantly of atherosclerotic origin. The presence of a large neck, calcification, and atheroma formation within GIAAs all prevent safe surgical clipping or endovascular coiling, the current standards of care in the treatment of intracranial aneurysmal disease. Although accounting for

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only 5% of all intracranial aneurysms, the natural history and prognosis of GIAAs is dismal.[16] Natural history studies have demonstrated >50% risk of rupture and mortality rates of 68% to 100% at 2 years for untreated GIAAs.[15,17] We believe EC-IC bypass with parent vessel occlusion is the best surgical alternative, with dramatically improved mortality rates (3%-10%).[8,9]

There are two options when performing EC-IC bypass. The first involves a direct anastomosis from the STA to an intracranial artery (STA-IC), and the second requires the use of a conduit, either great saphenous vein (GSV) or radial artery (RA), to bypass from the common carotid artery (CCA) or external carotid artery (ECA) to an intracranial artery (CCA-IC or ECA-IC).[7,9-11,18-20] The STA-IC bypass is known as a low-flow bypass due to the smaller diameter of the STA and may not be adequate when performing a bypass to a high-flow vessel such as the horizontal segment (M1) of the MCA or the intracranial ICA.[8,14,21] In 1971, the first CCA-IC bypass was described using GSV as the conduit,[22] and the safety and effectiveness of this high-flow bypass was confirmed in many different studies.[11,12,18,23-25] Flow rates are higher with GSV than with RA, which may not be advantageous when inserting into branches of the MCA that are <2 mm because this may cause a flow disturbance.[16]

EC-IC bypass using GSV or RA is a technically challenging procedure that requires vascular and neurosurgical expertise. In our previously published series,[9] we presented the surgical technique and safety profile in 29 patients with GIAAs who were successfully treated with EC-IC bypass, followed by immediate parent vessel occlusion. Our current series is a continuation of the previous study and now includes 36 patients with GIAAs who were treated with EC-IC bypass, followed by immediate parent vessel occlusion. All EC-IC bypasses were performed by the same neurosurgeon (J.J.) and vascular surgeon (M.A.). Despite the advances in endovascular and neurointerventional devices (eg, the pipeline embolization device) and techniques, some patients still require EC-IC bypass.[26] This report summarizes the indications for surgery, imaging evaluation, operative technique, and outcomes in patients who underwent EC-IC bypass with a specific focus toward the role of the vascular surgeon.

METHODS

A retrospective review of patients treated from 1990 to 2010 at New York University Medical Center was performed after obtaining Institutional Review Board approval. We identified 36 patients, and their office and hospital records were reviewed with attention to age and sex, presenting symptoms, preoperative testing, procedure performed, type of bypass conduit, graft patency, intraoperative and postoperative complications, length of follow-up, and overall outcome.

Treatment algorithm. All 36 patients underwent magnetic resonance imaging or computed tomography scanning, or both, of the brain and cerebral angiography in conjunction with occlusion xenon blood flow tomography or balloon test occlusion. The indication for bypass in 33 patients was failure of xenon blood flow tomography, defined as cerebral blood flow <30 mL/100g/min, or of balloon test occlusion, defined as development of a neurologic deficit during a 20-minute parent vessel occlusion. In the remaining three patients (four aneurysms), the indications for bypass included a giant aneurysm of the contralateral cavernous carotid artery eroding into the sphenoid sinus, progressive hemiparesis secondary to hemodynamic insufficiency from a previously sacrificed ipsilateral CCA, and a giant vertebrobasilar aneurysm without collateral circulation from the anterior system.

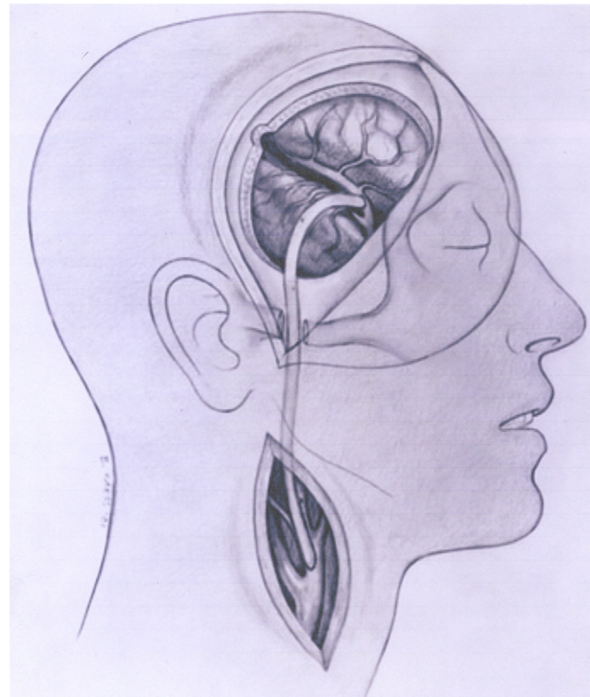

Fig. Surgical technique for extracranial-intracranial bypass using great saphenous vein (GSV) or radial artery grafts. Reproduced with permission from Jafar et al.[9]

Surgical technique. For high-flow bypass, a long segment of GSV or RA was used as the vascular conduit with the technique depicted in the Fig. The GSV was harvested between the ankle and the knee and marked with a sterile pen to prevent twisting during subsequent tunneling. All vein bypasses were reversed, thus eliminating the need to remove valves with the valvulotome, which may cause endothelial damage. The disadvantage of this technique is that it may be difficult to obtain equivalent donor and graft lumen sizes. This was overcome by choosing a segment of vein that was relatively uniform in diameter and of an appropriate size match for the intracranial vessel. Any venous side branches were ligated with 5-0 silk ties. It has been published that GSV patches are prone to aneurysmal degeneration in the setting of carotid endarterectomy[27]; however, we are unaware of any reports of aneurysmal generation of GSV grafts used as a vascular conduit in EC-IC bypass.

The RA was dissected between the elbow and wrist, and all side branches were ligated, as with the GSV. One advantage of using RA is that there is a uniform diameter throughout the length of the conduit. In the later portion of our experience, we transitioned to using RA when feasible because long-term studies in coronary artery bypass grafting have demonstrated superior patency compared with GSV.[28]

The vascular conduit was kept in situ until the proximal and distal anastomotic sites were prepared. Next, the CCA, ICA, and ECA were exposed through a cervical incision over the anterior aspect of the sternocleidomastoid muscle. A pterional craniotomy was performed with dissection of the sylvian fissure. A passage was created by removing the posterior portion of the zygoma using a rotating burr to allow tunneling of the graft in the preauricular position. The tunnel is created from the apex of the cervical incision to the zygoma, with care taken to avoid an acute angulation of the conduit as it passes posterior to the parotid gland. At this point, the graft was harvested and tunneled from the cervical to the cranial incision using a large vascular trocar. The patient was given heparin (0.5 milligrams per kilogram) to maintain an activated clotting time of two times control. Dexamethasone (10 mg) and barbiturates were administered until burst suppression was obtained on electroencephalography.

The distal anastomosis was performed first, end to side with 8-0 or 9-0 monofilament nylon in a running fashion, to minimize temporary occlusion time and to allow maneuverability to perform the anastomosis with 360° visibility. To estimate the length of the conduit that would be needed, the graft was distended with heparinized saline and the excess trimmed using Potts scissors. Finally, the proximal anastomosis was performed. Whenever possible, to preserve distal collaterals, the proximal anastomosis was performed end to side to the ECA using 7-0 monofilament nylon sutures in a running fashion. If anastomosis to the ECA was not possible, secondary to early branching or inappropriate graft angulation, an end-to-side anastomosis to the CCA was performed.

Before blood flow was restored to the brain, a 25-gauge needle was inserted into the hood of the distal anastomosis with initiation of blood flow proximally. The distal end of the conduit was clamped, which allowed air to vent through the needle, thus preventing air embolism to the brain. The distal clamp was removed and a hemostatic agent placed over the 25-gauge needle hole.

During the last 13 years, we have performed intraoperative angiography after proximal native ICA clamping (eliminating competitive flow) to demonstrate graft patency and to evaluate anastomotic sites. After completion angiography, the proximal ICA clamp is removed, allowing for the return of competitive flow. Finally, the parent vessel was proximally ligated and anticoagulation reversed with protamine. Although the parent vessel was not ligated distally, all of the aneurysm still thrombosed.

Table I. Patient demographics and clinical findings

Variable	*No. or median (IQR)*
Patients	36
Male	14
Female	22
Aneurysms	37
Age, years	57 (49-66)
Aneurysm location	
Internal carotid artery	30
Paraclinoid	13
Cavernous sinus	10
Posterior communicating artery	7
Middle cerebral artery	4
Basilar artery	3

IQR, Interquartile range.

Table II. Surgical outcomes and complications

Outcome	*No.*
Location of proximal anastomosis	
External carotid artery	31
Common carotid artery	6
Location of distal anastomosis	
Middle cerebral artery	30
M1	3
M2	26
M3	1
Internal carotid artery	3
Superior cerebral artery	2
Posterior cerebral artery	2
Graft patency	
Patent	33
Not patent	4
Complications	
Hemianopsia	1
Transient hemiparesis	1
Death	2

All patients received aspirin (325 mg) in the recovery room and daily thereafter. Postoperatively, magnetic resonance angiography was used to evaluate the bypass, and when there were questions, a digital subtraction angiography was performed.

RESULTS

A total of 36 patients (14 men, 22 women) underwent 37 EC-IC bypasses using 34 GSV grafts and three RA grafts. The median age was 57 years (interquartile range, 49-66 years), and the median follow-up time was 53 months (interquartile range, 27-77 months). Aneurysm location was the ICA in 30 patients, the basilar artery in three, and the MCA in four (Table I). All 37 aneurysms were excluded from the cerebral circulation, with 33 grafts remaining patent at follow-up, as determined by follow-up serial cerebral or magnetic resonance angiography. At follow-up, 30 of 34 GSV grafts (88%) and all three RA grafts (100%) were patent (Table II).

Four graft occlusions (10.8%) occurred, all of which were in the GSV group. One graft occlusion occurred in a patient who underwent two-stage bilateral EC-IC bypasses for a bilateral giant cavernous aneurysm. During the second bypass procedure, a cranial pin was placed close to the graft, which stretched the skin and compressed the bypass, causing the graft to occlude. Nevertheless, collateral flow was sufficient and the patient remained asymptomatic. The other three graft occlusions were secondary to poor distal runoff. In these patients, the completion angiogram at the end of the case demonstrated sluggish flow, despite proximal cross-clamp of the native ICA, without evidence of stenosis or technical error.

We found that all bypass grafts that stayed patent for >10 minutes had very good long-term patency. Proximal parent artery occlusion was sufficient to completely thrombose most aneurysms. The two aneurysms that did not immediately thrombose did so on 3-month follow-up angiography. These aneurysms did not thrombose immediately because there was back flow from the graft into the aneurysm.

Morbidity and mortality. Two deaths (5.6%) occurred in this series. One death was secondary to a subarachnoid hemorrhage in a patient who initially presented with a stroke and was found to have a giant basilar artery aneurysm. The patient underwent ECA-posterior cerebral artery bypass with GSV, followed by bilateral vertebral artery coil embolization. The bypass was patent postoperatively, but the patient developed locked-in syndrome and eventually died. The second death occurred in a patient who underwent ECA-MCA bypass, with a prolonged temporary occlusion time of 60 minutes for the distal bypass vs the average temporary occlusion time of 20 minutes. The graft was patent postoperatively, but the patient developed a large left hemispheric cerebral infarction and died.

Postoperative graft occlusion led to homonymous hemianopsia in one patient and temporary hemiparesis in another (5.6%). Graft occlusions were asymptomatic in two patients. In all remaining patients, there was no change in neurologic status or clinical status after EC-IC bypass, as assessed by the senior neurosurgeon (J.J.).

DISCUSSION

Endovascular treatment of intracranial aneurysmal disease has progressed significantly in recent years and is the preferred treatment method at most centers, with surgical clipping reserved for patients in whom endovascular treatment fails or is not technically feasible.[4,29,30] There remains a subset of patients with intracranial aneurysms (ie, GIAAs) for whom endovascular treatment options are not yet developed and in whom surgical clipping is not only technically difficult but is also associated with a high percentage of morbidity and mortality.[31] GIAAs have always posed a therapeutic challenge because neither endovascular coiling nor surgical clipping is an option and endovascular stenting often leads to recanalization and treatment failure.[32,33] EC-IC bypass is an attractive method for treating GIAAs because the aneurysm can be completely isolated from the cerebral circulation via parent vessel occlusion while still maintaining high-velocity blood flow, especially if GSV or RA is used as the conduit.

Furthermore, EC-IC bypass has been demonstrated to be a relatively safe procedure, with acceptable morbidity and mortality rates.[8,14,19,34] Our data demonstrate that EC-IC bypass is a safe and effective treatment for GIAAs, with acceptable rates of morbidity (5.6%), mortality (5.6%), and graft patency (89.2%). We suggest that for treatment of GIAAs, the technique described in this report should be routinely used in centers where neurosurgery and vascular surgery services are available and should be considered a standard procedure in the armamentarium of the vascular surgeon.

Given the excellent safety profile of EC-IC bypass, it has been suggested that the use of this technique should be re-examined for the treatment of cerebral atherosclerotic vascular disease.[35] The determination that EC-IC bypass was inferior to aspirin came from one randomized study in 1985.[13] The studied bypass was the STA-MCA bypass, which is a low-flow bypass and does not provide sufficient flow to large intracranial arterial branches (eg, ICA, MCA, M1, or M2).[8,14,21] There has been hope that with our new understanding of cerebral blood flow requirement, that EC-IC bypass may benefit patients with intracranial cerebral atherosclerotic vascular disease, especially in the subset of patients with impaired cerebral hemodynamics.

A 2010 Cochrane Database review by Fluri et al[35] found that EC-IC bypass was neither superior nor inferior to medical therapy alone in a review of 2591 patients in 21 trials, including two randomized controlled trials. Most of the studies in the review included patients in whom no stratification was performed to separate patients with embolic stroke and sufficient intracranial hemodynamics from those patients with ongoing hemodynamic compromise.

The Japanese EC-IC Bypass Trial, a randomized trial of patients with severe hemispheric hemodynamic failure caused by cerebral artery occlusive disease, was performed to address this issue; however, this study failed to demonstrate a clinical benefit in the primary outcomes of "death from all causes" and "any stroke."[36]

The Carotid Occlusion Surgery Study (COSS) was performed to determine if EC-IC bypass added to best medical therapy would reduce the incidence of ipsilateral ischemic stroke in patients with recently symptomatic atherosclerotic ICA occlusion.[37] The COSS trial was a parallel-group, randomized, open-label, blinded-adjudication clinical treatment trial conducted from 2002 to 2010 in which 195 patients with angiographically confirmed atherosclerotic ICA occlusion were randomized to receive surgery (97 patients) or no surgery (98 patients). For the surgical group, EC-IC bypass was performed using the STA to an MCA cortical branch. The primary end points of the study were "all stroke and death" and "ipsilateral ischemic stroke." The trial was terminated early for futility because the 2-year rates for the primary end points were 21% in the surgical group and 22.7% for the nonsurgical group (P = .78). The 30-day ipsilateral ischemic stroke rate was 14.4% for the surgical group and 2% in the nonsurgical group. Graft patency was 98% at 30 days and 96% at the last follow-up (median follow-up, 723 days). The authors concluded that despite excellent graft patency and improvement in cerebral hemodynamics, that EC-IC bypass provided no additional benefit compared with medical therapy for preventing recurrent strokes.

CONCLUSIONS

Current literature reaffirms there is no role for EC-IC bypass in the treatment of intracranial ischemic disease. However, despite the advent of new endovascular techniques, EC-IC bypass must remain in the armamentarium of both vascular and neurosurgeons for the treatment of selective GIAAs.

AUTHOR CONTRIBUTIONS

Conception and design: RG, JJ, MA
Analysis and interpretation: RG, JJ, MA
Data collection: RG, HH
Writing the article: RG, HH
Critical revision of the article: RG, JJ, MA
Final approval of the article: RG, HH, JJ, MA
Statistical analysis: RG
Obtained funding: Not applicable
Overall responsibility: MA

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